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GRADE ORES

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Walter W. Bradley.

METALLURGICAL TREATMENT OF THE LOW-GRADE AND COMPLEX ORES OF UTAH

A PRELIMINARY REPORT

BY

D. A. LYON, R. H. BRADFORD, S. S. ARENTZ,
O. C. RALSTON, and C. L. LARSON

ISSUED JOINTLY BY THE BUREAU OF MINES AND THE DEPARTMENT OF METAL-
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METALLURGICAL TREATMENT OF THE LOW-GRADE AND COMPLEX ORES OF UTAH.

INTRODUCTION.

By D. A. LYON.

In the performance of its duty of conducting investigations to increase safety, efficiency, and economic development in the mining and treatment of ores and minerals the Bureau of Mines is cooperating with various State organizations in order that the necessary work may be done to best advantage and without duplication of effort.

At its tenth regular session in 1913 the Legislature of the State of Utah provided for the establishment of a metallurgical research department in connection with the State School of Mines of the University of Utah. The act^a providing for this department stated:

The purposes of this research department shall be to conduct experiments and researches, either alone or in cooperation with the National Bureau of Mines and other agencies, with a view of finding ways and methods of profitably treating low-grade ores, of obtaining other information that shall have for its object the benefit of the mining industry and the utilization and conservation of the mineral resources of the State, and to publish and distribute bulletins and articles relating to the department and its work.

The station has effected a working arrangement with the Federal Bureau of Mines by which the bureau is furnishing the metallurgist, who has charge of the research department, and an assistant metallurgist. The University of Utah is providing the buildings and equipment and also five metallurgical research fellowships of the yearly value of \$720 each. The fellowships are awarded to graduates of colleges, and preferably mining schools, who have shown special aptitude for research investigations. Holders of the fellowships are required to work on the bureau time schedule, except Saturday, when they quit at noon. Their employment extends over the entire 12 months.

The fellows selected by the university authorities for the fiscal year 1913-14 were: L. F. Pattison, A. B., University of Utah; W. G.

^a Laws of Utah, 1913, ch. 102, sec. 2, pp. 199-200.

Woolf, A. B., University of Utah; O. H. Pierce, A. B., University of Nebraska; A. E. Gartside, A. B., University of Oklahoma; and C. Y. Pfoutz, E. M., University of California.

Messrs. Pattison, Gartside, and Pfoutz resigned their fellowships at the end of the fiscal year, and those selected, from a large number of applicants, to take their places for the fiscal year 1914-15 were: R. M. Isham, Ph. D., Columbia University; C. L. Larson, E. M., University of Minnesota; and H. J. Morgan, A. B., Stanford University.

All of the men mentioned actively aided in obtaining the data used in preparing this report.

Attention is called to the fact that this report is a preliminary statement only. Much work must be done to determine the applicability or the precise value of most of the different methods of ore treatment that are mentioned.

THE PROBLEM OF UTAH'S LOW-GRADE ORE.

By ROBERT H. BRADFORD.

REVIEW OF MINING IN UTAH.

When the ores from the head of Little Cottonwood Canyon were shipped by wagon to San Francisco and by boat from there to Swansea, Wales, their value per ton was necessarily high. These were surface ores, and the value decreased with depth. However, at the Emma and neighboring mines at Alta, the ores continued of sufficient value to warrant shipping by team to Omaha and thence by train to the smelters at Chicago. Early mines in other districts added to the amounts shipped to the distant smelters, but none of the mines of these districts yielded ores of enormous value, as have many of the mines of the neighboring States. Utah's high standing as a mining State has resulted from her enormous supply of medium and low grade ores.

GOLD.

Utah has produced some free-gold ores, but these were seldom very rich and were never found in any considerable quantity. The gravels of Bingham Canyon yielded placer gold for a time, as did also gravels near some other early mining camps. Mines near Richfield, in Sevier County, produced some "picture rock" and ore containing enough finely disseminated free gold to pay handsomely when cyanided. A few other districts have produced some gold, but Mercur has given by far the greatest returns as a strictly gold camp. The gold ore of Mercur was low grade and could not have been treated profitably but for the advent of the cyanide process, just when all old processes had failed. So even in the case of gold ores the State of Utah has produced the lower grades.

SILVER.

Silver ore richer than that now mined was common at most of the early camps. Later developments showed increased tonnage, but of lower grade. From the first mining efforts in Utah the State has ranked high in silver production. To-day much low-grade silver ore awaits some cheap method of treatment.

LEAD.

Lead ore mined for lead alone must carry a high percentage of the metal to have much value per ton. In Utah the lead ores mined have been rich in silver, and it was the combined lead and silver content that made the ores valuable. Much low-grade lead ore and lead-zinc-silver-gold ore is awaiting some cheaper method of treatment.

COPPER.

For the first 20 years of the State's mining history the red metal, copper, was not considered valuable. In the last 20 years the copper production has increased until now Utah ranks a close fourth among the States of the Union in the production of that metal. Low-grade copper ores are the source of the copper.

ZINC.

Up to date no zinc smelter has been built in Utah, but not because the ores mined contained no zinc. To keep down the zinc content, because of the penalty charged by the smelters, has been the important aim of the ore shipper. Now the proportion of zinc is increasing and the zinc must be considered as a possible source of profit in mixed sulphide ores and also in oxidized ores. Occasionally the percentage of zinc is sufficient to make the ore worth shipping direct to zinc smelters, but the amount of such ore found has been small. Zinc ores, so long considered as of no value, now bid fair to become a big source of income if methods of profitably treating the low-grade ores can be discovered.

IMPROVEMENTS IN MINING AND METHODS OF TREATMENT.

The first smelting furnace was erected at Bingham with the hope that the cost of mining and smelting would be less than \$100 per ton, which had been the cost of mining, shipment to Chicago, and smelting there. Actually, the cost with this furnace was kept down to \$89 per ton, and as improvements in design and operation were made the cost was still further reduced.

As the mining and treatment costs were lowered, ores of less value were mined at a profit. During the seventies ores valued below \$40 to \$50 per ton were considered too low grade to save. In the early nineties methods had been so improved that \$20 ore was successfully handled, and under favorable conditions \$16 ore. Ten years later \$8 to \$9 ore was worked and under certain conditions a profit was made on \$6 ore.

With the enormous deposits of low-grade ores the principal problem demanding attention is still, as before, the devising of cheaper methods of mining and treatment.

PORPHYRY MINING AT BINGHAM.

It is interesting to note the results of the improvements already made. Compare, for instance, the costs for mining and smelting high-grade ore at Bingham in 1872^a—\$89 per ton—with the costs for ores at the same camp 41 years later, when the porphyry copper ores were mined, milled, and smelted for \$1.25 per ton.

In order to bring the costs down to this figure the Utah Copper Co. is conducting work on a mammoth scale. The company is mining an entire mountain, the largest developed ore body in the world, and has an enormous equipment. Fifty-one locomotives and 22 steam shovels are day and night engaged in tearing down the ore. Every 24 hours about 24,000 tons of ore and nearly double this amount of overburden are moved, the pay ore to mill bins, the waste to near-by gulches.

The feat of solving the problem of treating these ores was accomplished by careful and painstaking experimental research on the part of the management of the company. Success was largely due to its ability to anticipate the results of mining and milling on a scale commensurate with the immensity of the low-grade ore body in the monzonite-porphyry it had carefully prospected. The company has expended \$25,000,000 in improving its property, and produces yearly 8,000,000 tons of ore, from which it extracts over 150,000,000 pounds of copper. These results illustrate the application on an enormous scale of methods devised for one class of Utah's low-grade ores.

However, the Utah Copper Co. still has its problems. Enormous quantities of monzonite are mined and treated at remarkably small cost per ton, but the fact remains that the saving is low. For each 2 pounds of copper recovered by milling, a third pound goes to the dump. To better this saving while keeping the cost of treatment at a minimum is the company's constant effort.

Considerable of the ore shows a mixture of sulphides and oxides of copper. To keep the oxides from going to the tailings and being wasted requires a different treatment from that now employed in the two mammoth mills. A method of leaching combined with flotation is being worked out for this ore.

The oxidized capping as a rule carries considerable copper, in many places as much as the porphyry ore, and the copper-bearing capping is kept separate from the more barren waste rock that has to be removed. The treatment of the enormous amount of low-grade ore in this capping is a gigantic problem. More than 40,000,000 tons of such ore is awaiting treatment by a process that will successfully and economically recover the contained metal. If such

^a Boutwell, J. M., *Economic geology of the Bingham mining district, Utah*: Prof. Paper 38, U. S. Geol. Survey, 1905, p. 90.

ores be leached, as they probably will be, it will be necessary to employ a process that can be applied on a scale commensurate with the size of the deposit.

TREATING STOPE FILLINGS AT PARK CITY.

In the Ontario mine at Park City, Utah, the material of too low a grade to be treated at a profit was either not mined or was stored in stopes, or rooms, underground. To-day, because of improved methods of treatment, these old stope fillings and the low-grade ores in place are being profitably mined and milled. The management states that the new mill of the Mines Operating Co. treats 150 tons of ore a day. Similar ores in the near-by mines are amenable to the same process of treatment and will no doubt be economically worked in mills now being designed.

LOW-GRADE ORE IN THE TINTIC DISTRICT.

In the Tintic district the better-grade ores have been shipped to the smelters in the Salt Lake Valley, or else have been milled. Some of the early methods of milling were quite crude. Ores high in silica, and hence hard to smelt, that carried a metal content valued at less than \$10 per ton, were either left in the mine or stored on the dumps. These low-grade deposits are known to be large. Of late much research has been conducted with a view to devising some method of treating these ores. A mill is now being tested in Silver City which bears promise of giving desired results.

The three districts mentioned are the largest in Utah, and their untreated ores have been measured in tons. Ores in smaller camps promise much profit when cheap methods of handling and treating are worked out. The "porphyry ores" of the mammoth deposits at Bingham remained uninviting for years.

Ore, after all, is a relative term, one definition being as follows: "A metalliferous mineral containing metals in sufficient proportions to be profitably extracted." Hence minerals that once were discarded as waste may later be classed as ore, and material that is considered valueless in one region may be deemed ore in a region more favorably situated. The deciding factor in the classification is the cost of treating the material to obtain its marketable product.

SITUATION AND EXTENT OF THE LOW-GRADE ORES.

By S. S. ARENTZ.

In considering what investigations would be most profitable to take up in connection with the low-grade ore problem it at once became evident that each low-grade ore presents its own problem and that a survey of the State to determine the location and extent of the developed low-grade ore deposits was necessary. Considerable time

and attention have been given to the examination of reported large low-grade ore deposits and tailings dumps. Some of them have proved to be most inviting, whereas others have not. A report of the results of the examinations made of the mining districts visited is given here.

EXAMINATION OF THE MINING DISTRICTS.

BINGHAM AND GARFIELD.

The mammoth deposits of monzonite porphyry^a at Bingham, previously mentioned, carry small percentages of copper, silver, and gold. The ore is low grade, but is mined in great quantity and is treated by concentration and smelting. The tailings, which carry 0.6 per cent copper, make an enormous pile. Over 30,000,000 tons of this material now collected may yet be re-treated.

The ore under the capping and above the sulphides, consisting of oxides and sulphides intermixed, will need special treatment. A combination of flotation and leaching is suggested.

The oxidized ore of the capping has been carefully saved and will doubtless be leached.

The treatment of pyritiferous ores with a low copper content has long been a problem of the mines in this district. When the zinc content is below 8 per cent this material smelts well in blast furnaces running "pyritically."

Ores high in silica and low in copper are sold to the smelters for flux in the basic-lined copper converters. If these ores could be leached to a better advantage, the district no doubt could supply a large tonnage of such ore. Complex sulphide ores are also produced in this district. Their treatment has long been a much-discussed problem. At the Midvale mill of the United States Co. the ore is concentrated, then the middlings are dried and treated electrostatically. The company ships a zinc concentrate east to the "gas belt," but smelts the lead concentrates and also the pyrite. Much ore of this class is demanding attention.

PARK CITY DISTRICT.

Mining has been conducted at Park City^b since 1869, and many dividend-paying mines have been developed, so that operators in that district are rather averse to admitting that anything like a low-grade or complex ore problem exists there.

^a For a discussion of the geology of the ore deposits, see Boutwell, J. M., *Economic geology of the Bingham mining district*: Prof. Paper 38, U. S. Geol. Survey, 1905, 413 pp.

^b For a description of the geology of the ore deposits, see Boutwell, J. M., *Geology and ore deposits of the Park City district*: Prof. Paper 77, U. S. Geol. Survey, 1912, 231 pp.

In this district there are three classes of ore, as follows:

1. Shipping ore.

Sulphide:

- (a) Silver-lead ore.
- (b) Silver-lead-zinc ore.
- (c) (Rarely) zinc ore.

Oxidized:

- (a) Silver-lead ore.
- (b) (Rarely) zinc ore.

2. Concentrating, or mill ore.

Sulphide:

- (a) Silver-lead ore.
- (b) Silver-lead-zinc ore.
- (c) Zinc-iron-lead ore.

Oxidized:

- (Rarely) silver-lead ore.

3. Low-grade oxidized ore.

- (a) Oxidized silver-lead ores.
- (b) Oxidized silver-lead-zinc ores.
- (c) (Rarely) oxidized zinc ore.

There is a large amount of each of the above classes of ore in the Park City and Alta districts. Owing to the nature of the deposits the total available tonnage could not be determined even approximately. The production of Park City for 1913 was approximately as follows: Shipping ore, 35,000 tons; concentrating ore sent to mills, 188,814 tons; concentrates, 41,970 tons. This production will be maintained for years, according to men who are familiar with the district. To lessen the economic waste resulting from present methods of treating these ores and mineral products will, in the aggregate, add millions to the wealth of Utah.

The five ores given under "Shipping ore" in the classification are resolvable into two classes as far as the smelters are concerned, namely, lead ore and zinc ore. The zinc remaining in lead ore brings no return to the shipper, and if it exceeds a certain percentage causes the ore to be penalized so that the shipper suffers a direct loss as well. Lead remaining in zinc ore represents a loss—in most cases a direct loss. The loss that occurs when treating ores such as those above mentioned is illustrated by a published statement of a Montana producer of zinc concentrate.^a

The recovery was high—90 per cent—and the grade of the concentrate was good—50 per cent zinc—but it contained also small percentages of lead and copper, with some silver and gold. The gross value of the merchantable metals,

^a Editorial; The western metallurgical field; the complex-ore problems: *Met. and Chem. Eng.*, vol. 12, September, 1914, p. 555.

based on current quotations, was about \$80 per ton of concentrate. The actual market value at the smelter was about \$24, leaving a difference of \$56. A part of this difference is accounted for in freight, smelting, and marketing charges, but much of it probably represents a loss to the producer due to economic conditions in the smelting industry. Such instances emphasize the limitations of present methods of concentration and increase the demand for new processes that are more efficient.

It is quite probable that the Park City district still has a long life before it, during which time ore will be shipped direct to smelters. The loss of lead in zinc ore and of zinc in lead ore during this period will amount to millions of dollars unless some process is devised for the saving of these metals.

In the milling of the Park City ores it is doubtful if any considerable part of the metals in oxidized ores sent to the concentrator is saved. This is acknowledged by the operators, yet such ore continues to be sent to the mill. If this oxidized ore is low in silver and gold content, and too low in lead and zinc to warrant shipping, it could not be treated by any known (commercially economical) process whereby a saving in lead and zinc could be made without a proportional economic loss—that is, a loss in smelting as well as in the tailings.

THE MILLING PROBLEM IN THE PARK CITY DISTRICT.

The problem constantly before the mill operators of Park City is to keep low the zinc content of the lead concentrates and the iron and lead content of the zinc concentrates. All the zinc in the lead concentrate is a loss to the operator and an economic loss to the Nation. The same is true of lead, copper, and other metals in the zinc concentrate.

That a problem does exist in the treatment of the milling ores of Park City is proven by the fact that for years the tailings carried down Empire Canyon and Woodside Gulch have been re-treated in a crude way by privately owned plants equipped with concentrating machinery similar to that in the company mills.

The tailings carried down these waterways are retarded at intervals by rough dams. From time to time the material caught above a dam is shoveled into piles, gathered into wagons, and hauled to a crude mill farther down the gulch, where the valuable minerals are extracted by means of jigs and tables. Enough of these minerals is extracted to leave a fair profit after it has been shoveled at least three times, hauled 1 to 3 miles, and treated.

A somewhat similar condition exists, perhaps, at any of the silver-lead-zinc concentrating plants throughout the Western States. That it does exist merely goes to prove that some losses occur even at such successful plants as those of Park City.

Other than the above-mentioned ores, there is a variety of oxidized ore containing 6 to 8 ounces, or more, of silver per ton and 0.5 to 1 per

cent copper. This ore may be the filling of fissures, replacement material at intersection of fissures, or a bedded deposit, and may be material derived from high-grade ore or may be a distinct body of low-grade ore.

THE METALLURGICAL PROBLEM IN THE PARK CITY DISTRICT.

Although it would not be commercially feasible to attempt a perfect extraction of all the valuable minerals from an ore, it would seem that a better extraction should be had than 50 to 66 per cent of the zinc content, as is stated to be obtained at the Park City mills. It is not meant by this statement that the mills are not operated according to good standards of mill practice, but rather that with even the best of mill practice there is a loss of metals, which if possible should be lessened. Such being the case, the problem is how to effect a better saving of the valuable minerals than is now being made and how to treat the low-grade oxidized ores, which are not at all amenable to concentration by the processes now being used.

A start in this direction has been made by the Mines Operating Co., which is treating the stope fillings of the Ontario mine. This oxidized material was considered as waste up to about two years ago. The American Flag mill was constructed to treat ore similar to the Ontario stope fillings, and the management contemplates the treating of custom ore from a number of Park City and Alta mines.

The treatment of the oxidized ores will add much to the gold, silver, and copper production of Park City, Alta, and similar districts. What was waste yesterday is a valuable source of these metals to-day, owing to the application in a new way of an old process—chloridizing, roasting, and leaching—to these ores. All the oxidized ores of this district contain some lead and zinc, as previously stated. In the present treatment of these ores no zinc is saved and only a very small part of the lead. Ofttimes the value of these two metals is greater than the gold, silver, and copper saved. As long as this condition exists these ores will present a problem well worthy of all the time and money given to its solution.

TINTIC DISTRICT.

The Tintic district^a includes all the mines adjacent to Eureka, Knightsville, Mammoth, and Silver City. Shipments from this district have continued since 1870.

The Tintic district is considered as being a silver-lead district, although the ores mined can be divided into four classes: Highly siliceous gold ore, gold-silver-lead-copper ores, gold-silver lead ores,

^a For a description of the geology of the ore deposits, see Tower, G. W., jr., and Smith, G. O., *Geology and mining industry in the Tintic district*: 19th Ann. Rept., 1897-98, U. S. Geol. Survey, 1899, pp. 601-767.

and oxidized zinc ores containing small amounts of silver and lead. Primary sulphide ore in any quantity has not been encountered in the district.

On account of the large proportion of sulphide ore and concentrates shipped to the Salt Lake smelters, siliceous ores are in demand. Hence siliceous ores are shipped from the Tintic district in large quantities. A few years ago such siliceous ore was not considered milling ore unless the value of the metal content was over \$20 per ton.

The ores as mined in the district consist of highly siliceous gold ore, high-grade silver-lead ore, siliceous silver-lead ore, oxidized zinc ore, and, rarely, copper ore. In mining high-grade silver-lead ore, generally the amount of lower grade oxidized material encountered is much larger than the amount of high-grade ore extracted.

The oxidized ores now comprise the bulk of the ore shipments from Tintic. The amount of sulphide ore mined is small, most of it being high-grade lead ore varying in its silver content. The zinc ore, for the greater part, is encountered in the development and extraction of the two classes of silver-lead ore, generally as separate stopes in the footwall of the silver-lead ore or as linings to silver-lead stopes. In addition to the classes of ore mentioned, there is encountered with them ores of low grade. If the valuable minerals in this low-grade material are contained in scattered lumps of lead sulphide, or oxidized lead, the mineral is sorted either by hand picking or by screening, depending on the fineness of the pay ore. The rejected fines contain gold, silver, copper, and lead to the value of \$2 to \$8 per ton, with general averages of \$5 to \$6 per ton. In addition to this class of material, large quantities of highly siliceous ore, of an average value of \$6 per ton, have been developed in the search for higher grade ore. In some parts of the district the siliceous ore carries chiefly lead and silver, and in others it carries gold, silver, and lead, or gold, silver, copper, and lead. Nearly all the mines contain some siliceous ore.

It is estimated that the Tintic district contains at least 2,000,000 tons of low-grade copper-lead-silver-gold ore, which assays approximately as follows: Gold, 0.10 ounce per ton; silver, 4 ounces; lead, 1 to 3 per cent; copper, 0.5 per cent.

The Knight-Christensen mill, above Silver City, was constructed to treat this class of ore. The mill has a capacity of approximately 100 tons a day, and the process used aims at effecting a large saving of the gold, silver, and copper. The lead is brought into solution, but at this writing little lead is saved, because a method of economically precipitating that metal has not yet been devised. In the aggregate an appreciable quantity of lead is lost in this manner. This problem is receiving considerable attention.

Nearly all the mines in the Tintic district have more or less zinc ore, either in separate stopes adjoining the lead stopes or as shells in the lead stopes. The zinc ores are all oxides and contain small amounts of lead and silver.

The Yankee Consolidated, May Day, Uncle Sam, and Mammoth mines report oxidized zinc ore in excess of 200,000 tons. The zinc content ranges from 5 to 25 per cent. During the year 1913 a total of 6,457 tons of zinc ore was shipped. The average zinc content was 33.06 per cent. Under present conditions it does not pay to ship such oxidized ore containing less than 30 per cent zinc, if the price of spelter is below 5.5 cents per pound. The problem presented here is the devising of a method for the treatment of these low-grade zinc ores; also for the extraction of the zinc contained in the lead-silver ores shipped.

STOCKTON DISTRICT.

For some years past the only shippers from the Stockton district have been the Bullion Coalition and the Ben Harrison mines. The Ben Harrison ore is shipped to smelters and as far as can be determined at this time (February, 1915) no bodies of low-grade ore of any moment have been encountered.

At the Bullion Coalition mine about 50 tons of silver-lead-zinc-iron pyrite ore are treated daily. The mill is of the ordinary type of lead-concentrating plant. The ore is very high in iron sulphide. No zinc concentrate is made, the lead being separated from the iron pyrite and zinc without much difficulty. The concentrates contain about 9 per cent zinc; the rest of the zinc goes into the tailings.

In the early operation of this plant oxidized ores formed the major part of the material sent through the mill. It is estimated that the tailings dump contains approximately 175,000 tons. About one-half of this quantity is oxidized material. The balance, forming the top layer of the dump, consists of lead-zinc tailings containing a high proportion of iron, about 23 per cent, in the form of pyrite. These tailings have a gross value, in gold, silver, lead, and zinc content of about \$10 per ton. The zinc is combined chemically with a high percentage of iron. The material in these tailings defies economical separation of the contained lead and zinc minerals by ordinary methods, except through the application of one or more processes, such as roasting, magnetic separation, or flotation, combined with hydro-mechanical processes.

In the Stockton district a large supply of oxidized zinc ore is reported. In the Old Honerine mine the oxidized ore extends to the 700-foot level; from the 700 to 1,300 foot level, the deepest workings, the ore is a mixture of lead and zinc sulphides. The oxidized zinc ore is of little value unless some means of concentrating it before

shipment can be found. The zinc in the lead concentrates is an economic loss. Some cheap and efficient means should be found for treating the tailings and saving all the metallic contents.

DRY CANYON AND OPHIR DISTRICT.

Dry Canyon can be made a producer of low-grade zinc ore if a method is devised for economically treating the mixed carbonate and silicate of zinc. A considerable quantity of this ore is found in the old workings. Much more could probably be developed if it were profitable to mine low-grade zinc ores. In mining this low-grade zinc ore much of the profit would undoubtedly be spent in the development of new workings, particularly at depth, so that new mines would actually be made from the profit derived from material considered waste at the present time.

Approximately 120 tons of tailings daily are being produced in the Ophir Hill Consolidated mill. According to the management 750,000 tons of tailings accumulated on the dumps in Ophir Canyon during the past 12 years.

These tailings are said to assay as follows: Copper, 0.65 per cent; lead, 0.74 per cent; zinc, 4 to 5 per cent; silver, 2.78 ounces per ton. The concentrate produced from the crude ore contains approximately 7.5 per cent zinc, for which the shipper receives nothing.

DEEP CREEK DISTRICT.

With the exception of the Western Utah mine and several gold mines, sufficient development work has not been done in the Deep Creek district to enable one to judge whether there will be a low-grade or complex ore problem. Numerous fissures from 2 to 6 feet wide have been partly developed throughout the granite area. Some rich lead ore has been mined at a number of places. The material on the dumps is highly siliceous and the sulphide ores are an intimate mixture of lead-zinc and iron sulphides. More development work will have to be done to prove the possibilities of this district. The treatment of the gold, bismuth, copper, or silver-lead-zinc ores, from the partly developed properties presents no especial difficulties, except that water had to be brought long distances, and the district is 50 miles from a railroad.

MILFORD DISTRICT.

The Milford district includes the Beaver, Frisco, Newhouse, and other properties adjacent to Milford. There are marked differences in the character of the different deposits. Ores are found in quartz-monzonite which are similar to those mined by the Utah Copper Co.

at Bingham; ores are also found in the sedimentary rocks and in volcanic rocks.

The quartz-monzonite type of deposit is represented by the Cactus ore zone and by the O. K. mine. Both of these properties have produced high-grade ore, but their present value lies in the extremely low-grade material making up the reserves of the mines. No tonnage is reported from the O. K. property. Various estimates have been made on the amount of ore in the Newhouse or Cactus district. The ore is a low-grade copper ore containing approximately 1.2 per cent of the metal. In the tailings dump there is estimated to be over 500,000 tons of tailings containing more than 4,000,000 pounds of copper.

Deposits in the sedimentary rocks are numerous. For the most part the ores mined from such deposits in this district have been high grade and only recently have low-grade primary ores been encountered. The operators report no considerable tonnage, and as far as could be determined no metallurgical problem presents itself except the economic loss represented by the zinc contained in the lead-silver ore shipped, and the lead in the zinc ore shipped.

The same condition exists in the mining region adjacent to Minersville and Beaver City. All the properties on which work is being done are in the prospect stage; at least there are no mines in the sense of having ore blocked out, except they be gold properties. Undoubtedly deposits of commercial value will be developed in some of the many old properties in the vicinity of Milford—ores that will be similar to some of those found in the Park City and Tintic districts.

Mineralization in the igneous or volcanic rocks has taken place at numerous places. There are two commercially important mines of this type in this section, namely, the Horn Silver and the Beaver Carbonate.

It is reported that the Beaver Carbonate mine, developed to the 700-foot level, has blocked out a quantity of low-grade silver-lead ore assaying 5 to 12 ounces of silver per ton and 6 to 10 per cent lead. A considerable quantity of material is represented by the tailings dump, but its estimated value could not be ascertained.

According to the general manager of the Horn Silver property, three ore problems are presented at that mine. These are:

1. The fillings of the old stopes, which consist of carbonate ore high in silica and assaying approximately as follows:

Lead.....	per cent..	12.0
Copper.....	do.....	0.7
Silica.....	do.....	52.0
Lime.....	do.....	8.0
Silver.....	ounces..	6.0

About 200,000 tons of such material is in the stopes down to the 750-foot level.

2. Low-grade sulphide ore left in the mine below the oxidized zone. This ore assays as follows:

Iron-----	per cent--	5.0-6.0
Zinc-----	do-----	20.0
Silica-----	do-----	60.0
Lead-----	do-----	10.0
Copper-----	do-----	0.3
Silver-----	ounces--	5.0

3. The old concentrating-mill tailings, of which there are approximately 190,000 tons, reported to assay about as follows:

Lead-----	per cent--	8.0
Zinc-----	do-----	7.0
Copper-----	do-----	0.4
Silica-----	do-----	61.0
Calcium oxide-----	do-----	8.0
Iron-----	do-----	5.0
Sulphur-----	do-----	8.0
Silver-----	ounces--	6.0

In 1905 a "Peck centrifugal concentrator" mill was constructed to treat these tailings, but after a run of a few weeks it was found the tailings could not be treated at a profit by this process. The mill was closed down and nothing has been done, in a metallurgical way, with these tailings since that time.

In order to treat successfully these ores and tailings some process will have to be devised that will make an economical saving of practically all the valuable metals contained therein. The fact that the tailings are finely ground adds to the difficulty of the problem. A large part of the lead is in the sulphate form and the separation of the lead and zinc is difficult. It seems necessary to devise a combination of processes for the treatment of these ores and tailings.

SILVER REEF DISTRICT.

Silver Reef district is the name given to an area containing a series of silver and silver-copper bearing sandstones in the central part of Washington County, Utah. The ore-bearing beds occur west, north, and east of Leeds. The ores are confined to what are locally called the Buckeye and White "reefs." North of Leeds the ore-bearing beds dip north; but to the east and west the strike and the dip changes until, at points approximately a mile east and a mile west of Leeds, the beds strike almost due south, are parallel, and dip away from a common axis, forming the flanks of an anticline. As far as exploratory work has been done, ore has been proven for distances of approximately $1\frac{1}{2}$ miles on the west flank and about 2 miles on the east flank. The outcrops can be seen for miles to the south.

The ores range from pure white sandstone, stained here and there with iron and carrying a high silver content, to sandstone colored

a deep blue from copper and carrying a high copper but a low silver content.

Men who have mined in this district claim that the high-grade silver ore seldom, if ever, contained copper, and that as the copper content of an ore increased the silver content decreased.

There are other beds that are slightly mineralized, but the inner or Buckeye Reef and outer or White Reef are the only productive ones. These two reefs are separated by several hundred feet of gypsum-bearing red beds. Both underlie the massive red sandstone which outcrops about a mile west of Leeds as a bold, vertical cliff 400 or 500 feet in height.

No effort to extract copper was made in the treatment of the Silver Reef ores. Neither was the treatment of silver ores containing less than 14 ounces per ton undertaken. Ores of this value containing appreciable amounts of copper were not treated.

Thus, in the Silver Reef district there are low-grade silver ores and also copper-silver ores. No work was done to determine the depth to which the ore may extend; when water was encountered work was stopped. The maximum dip of the "reefs" appears to be about 35° , but the dip is generally less. The deepest workings were in 650 feet from the outcrop.

There undoubtedly is a large amount of low-grade silver-copper as well as low-grade silver ore in this district. There is considerable virgin ground, and dumps containing a considerable amount of silver-copper ore that justifies attempts at treatment.

Silver Reef is 75 miles from a railroad; water is plentiful, but fuel is costly. If this ore were treated by the Holt process—chloridizing, roasting, and leaching—the costs would be too high, owing to the long haul on the coal and the chemicals necessary. For treating these ores a method would have to be devised which would use products to be had at low cost in the district. This would necessitate a study of the local natural resources in order to determine the presence of such necessary products.

Crude oil has been found near by in sufficient quantity, and filings have been made on water-power sites on the Virgin River.

EASTERN UTAH.

Copper ores in sandstone are to be found in eastern Utah from the Uintah Mountains to the Arizona boundary line. Few of these copper showings are of any economic importance. The erratic occurrence in eastern Utah of these copper ores in sandstone is a feature that tends to hinder their exploitation. The principal obstacles to their development are as follows: Variable copper content, distance from railroads, lack of water, and in most cases the smallness of the

deposit. If the copper content is high the deposit is small; if the deposit is large the copper content is variable. A large supply of ore of uniform grade is necessary if low-grade ore is to be mined at a profit. Cheap mining calls for a large tonnage. A number of disconnected lenses of ore have to be considered as a whole, and the development of one lens lends little or no value to an adjoining lens as far as the blocking out of the ore is concerned. Such a condition does not permit cheap mining, especially if the copper is scattered irregularly through the mass.

CHEMICAL CHARACTERISTICS OF THE UTAH ORES.

By O. C. RALSTON.

RESULTS OF ANALYSES.

The results of analyses of samples of complex and low-grade ores collected in connection with this investigation that seem to present distinct metallurgical problems are given in the table following. Ordinary free-milling or cyaniding gold ore, for instance, has not been investigated, as the treatment of such ore involves no special difficulties. But an oxidized ore carrying copper, gold, and silver in such amounts that there is too much copper to allow cyanidation or amalgamation, and too little copper, gold, and silver to be worth smelting, offers a distinct metallurgical problem. The following table of analyses represents samples of ores which so far have largely defied economical treatment.

Results of analyses of low-grade and complex ores.

[Analysts: L. F. Pattison, W. G. Woolf, O. H. Pierce, A. E. Gartside, C. Y. Pfoutz, H. J. Morgan, R. M. Isham, and O. C. Ralston.]

Sample No.	SiO ₂ .	CaO.	Fe.	Al ₂ O ₃ .	MgO.	Mn.	As.	S.	CO ₂ .	Zn.	Pb.	Cu.	Ag.	Au.	Bi.
	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Oz. p. t.	Oz. p. t.	P. ct.
1	12.9	9.75	7.56	6.2	.....	.....	.....	0.20	15.90	20.49	8.65	.....	0.45	Tr.	.....
2	10.6	8.20	33.00	3.3	.....	.....	.....	.....	13.19	8.6	.77	.....	.28	Tr.	.....
3	8.5	12.42	18.50	2.6	.....	.....	.....	.....	23.57	18.2	.....	0.1	.16	.....	.....
4	60.4	2.67	16.25	7.6	.....	.....	.....	.40	1.81	.87	9.02	.1	1.32	Tr.	.....
5	58.3	3.67	17.17	1.6	0.4	.....	.....	.74	4.77	.58	.....	.7	3.75	0.09	.....
6	81.2	.74	10.12	.9	.....	.....	.....	.....	.17	.78	.....	.4	5.53	.08	.....
7	94.1	.82	2.14	.6	.....	.....	.....	.....	.37	.58	.....	.1	5.30	.18	.....
8	69.0	2.45	13.08	12.8	.....	.....	.....	.....	2.60	.58	.05	1.04	7.06	.25	.....
9	69.5	2.56	8.38	2.7	.....	.....	.....	.....	6.18	.97	.....	1.22	3.15	.23	.....
10	52.7	2.30	11.75	5.8	.....	.....	.....	6.50	2.12	7.80	1.1	Tr.	1.80	.03	.....
11	80.8	.57	4.19	.7	.....	.....	.....	.....	1.05	.50	5.5	.....	7.90	.08	.....
12	81.9	1.39	4.50	Tr.	.....	.....	.....	.22	.52	.50	4.3	.....	2.80	.03	.....
13	31.4	10.25	4.19	Tr.	.....	.....	.....	.65	19.84	15.7	.55	.....	.30	.23	.....
14	51.3	4.90	12.47	8.0	1.7	.....	.....	.....	7.40	1.3	3.5	Tr.	9.55	.04	.....
15	76.6	2.05	5.72	3.6	.....	.....	.....	.....	2.29	1.8	.3	.75	6.71	.13	.....
16	59.6	.50	15.53	4.7	.....	.....	.....	.....	.07	.6	2.3	.2	4.42	.05	.....
17	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.02	.10	Tr.	.....
18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.87	Tr.	.....	.....
19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.57	.10	.....	.....
20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.47	.20	.....	.....
21	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.35	.....	.....	.....
22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.82	.1	Tr.	.....
23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	15.0	.2	.....	.....
24	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.6	.....	.....	.....
25	95.0	1.00	.50	2.1	Tr.	.....	.....	.....	.....	.....	.....	.....	10.48	.....	.....

Results of analyses of low-grade and complex ores—Continued.

Sample No.	SiO ₂ .	CaO.	Fe.	Al ₂ O ₃ .	MgO.	Mn.	As.	S.	CO ₂ .	Zn.	Pb.	Cu.	Ag.	Au.	Bi.
	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Oz. p. t.	Oz. p. t.	P. ct.
26												0.1			
27		1.00										2.1	12.18	Tr.	
28		1.50										.7	6.2		
29		2.60										.6	7.68		
30		10.00										.8	2.50		
31		1.00										.8	6.40		
32		1.00										3.3	10.32		
33		3.50										.9	.22		
34		1.80										1.6	.92		
35		1.40										2.7	3.68		
36		1.60										.4	2.68		
37		1.3										1.1	2.00	0.03	
38		1.9										.4	14.24		
39		13.8										1.4	2.76	.01	
40															
41													.21	.19	0.94
42															1.41
43															2.53
44															.09
45													.70	.06	3.17
46															
47	38.2	1.43	16.35	4.2				19.70		6.8	6.9	.6	40.59		.07
48	49.2	21.45	6.70	2.2					18.87			1.02	.20		.04
49	30.8	10.05	2.25	7.4			0.46	12.70	10.55	16.88	14.87	.72	29.56		.01
50	22.0	5.05	16.35	1.85			.20	24.75	6.48	12.0	15.39	.07	4.86		.04
51	43.3	3.20	5.30	21.6			.97	3.15	2.33	5.37	16.54	.62	17.90		.01
52	57.4	10.73	1.18	1.5		1.87		1.90	21.71	3.32	2.00	.07	4.66		.02
53	73.9	4.68	1.12	4.4		.37		.18	5.24	6.93	4.16	.11	15.94		.18
54	10.5	2.10	33.00	7.6			1.13	37.34		4.4	3.00	.10	.78		.01
55	9.3	3.40	28.8	15.8			2.33	35.86		8.5	10.47	.07	2.43		.02
56	14.0	2.10					1.69	33.26		11.4	2.59	.06	1.06		.01
57	12.5	1.10	15.00	8.6				.92	19.04	29.9	.21	.13	.15	Tr.	
58	18.0	1.10	22.2	14.6			2.42	30.32		13.1	10.56	.10	2.65		.02
59									3.00						
60	53.6	2.20	4.4	8.5		.37		6.13	1.37	6.3	7.4	.25	6.7	.02	

TYPES OF ORES ANALYZED.

The ores represented in the table of analyses may be considered as a number of distinct types classifiable on the basis of chemical composition, mineralogical constituents, as shown by microscopic examination; on information in the geological reports on these ores; on the action of dilute acids on the ores; and also on the history of metallurgical failures in treating these ores. Eight types of complex or low-grade ores may be distinguished, as follows:

1. Copper carbonate ores.

2. Oxidized ores carrying lead carbonate and silver. Samples 4, 11, 12, and 14 represent this class. In a number of places attempts have been made to concentrate such ores, but much of the lead carbonate was lost in the tailings on account of the habit of that mineral to divide into small flakes which tend to float off. Most of the ores contain over 50 per cent of insoluble material, but the amount of soluble iron and lime presents some difficulties to the application of hydrometallurgical processes. Analyses indicate that these ores, however, are markedly similar in composition (except for lack of copper) to the ore from the old Ontario stopes now being treated by the Mines Operating Co. at Park City, Utah.

3. Oxidized ores carrying small amounts of copper and lead as carbonates and also gold and silver. Samples 5, 6, 7, 8, 9, and 15 are representative of this class. As stated, this type of ore has not enough total value to make profitable at present its direct shipment to the smelter, and the presence of oxidized copper minerals render unprofitable the extraction of the gold and silver cyanide or amalgamate. Most of these ores are siliceous, but some of them show by analysis high content of lime and iron and might be classed as basic ores.

4. Oxidized ores with zinc as the chief constituent, and carrying occasionally gold and silver. This type of ore is represented by samples 2, 3, and 13. Most of these ores do not contain enough zinc to be accepted by the zinc smelters, and the oxidized zinc minerals present frustrate attempts to recover the gold and silver alone. The zinc content is too high to allow smelting in a lead or copper blast furnace. An oxidized ore in which zinc is the only valuable constituent must contain at least 30 per cent of zinc to be accepted by the zinc smelter, although some shipments of ore containing $22\frac{1}{2}$ per cent were made with spelter at 7 cents a pound, but none of the samples show even 22 per cent of zinc.

5. Oxidized ores with zinc and lead as the two chief valuable constituents, and occasionally carrying some silver and gold. This type of ore is represented by samples 1, 10, 52, and 53. In general, such ores contain too much zinc to allow smelting in a lead furnace and too much lead to allow smelting in a zinc retort. Moreover, the oxidized condition of the ores does not permit clean mechanical separation of the lead and the zinc minerals.

6. Oxidized ore containing zinc, lead, copper, gold, and silver. There is some of this type of ore in nearly all of the Tintic district mines, in the Horn Silver mine of the Milford district, and in the Park City mines. It is both low grade and complex, and it might be well to observe here that the "complexity" is generally due either to the presence of zinc or to the oxidized condition of the ore. It is practically impossible to separate mechanically the different mineral constituents of oxidized ores.

7. Any of the above groups only partly oxidized. Examples of such ores are samples 3, 51, and the copper ores of the Utah Copper Co. Such ores call for two kinds of treatment, namely, one for the sulphide minerals and one for the oxidized minerals, hence the complexity of this group.

8. Complex sulphides of zinc, lead, copper, and iron carrying silver and gold. These ores, which are represented by samples 47, 49, 50, 51, 54, 55, 56, and 58, are of common occurrence. As a rule the presence of zinc is the complicating factor, as a penalty is exacted by the lead and copper smelters if the zinc content is above a certain percentage.

Improvements in the methods of treating complex sulphide ores of this class are much to be desired in order that losses of zinc and lead may be avoided or turned into profits.

It may be said that the main metallurgical problem in Utah is to find processes which can successfully and economically treat great amounts of low-grade oxidized ores. Utah probably has more than an average share of such ores. There are, for instance, few large mining districts known in which the zone of oxidization extends so deeply as it does in the Tintic district. The oxidized minerals are, as a rule, soft and of lower specific gravity than the corresponding sulphides, and often are so intermixed as almost to defy any known kind of mechanical separation. On such ores as these, wet chemical processes should be the first ones to be considered, with the possible exception of the oxidized zinc ores. There seems to be a possibility of successfully treating the latter with certain forms of "igneous concentration."

METALLURGICAL TREATMENT OF THE ORES.

By D. A. LYON, R. H. BRADFORD, S. S. ARENTZ, O. C. RALSTON, and C. L. LARSON.

PROCESSES OF TREATMENT.

OXIDIZED ORES.

The present practice in the State as regards ores of type 2—those carrying lead carbonate and silver—is to recover all that can be recovered by ordinary methods of gravity concentration and to allow any flaky lead carbonate carried over to go into the tailings. The recovered lead carbonate is shipped to the smelter.

The Holt-Dern process at Park City and the Knight-Christensen process at Tintic were evolved for the treatment of ores of type 3. In these processes the ore is roasted with salt and the metals leached out with acid brine solution.

The ores of type 4, carrying oxidized zinc minerals as the chief constituent and occasionally some gold and silver, are not concentrated in any manner whatever at present, except by hand sorting at the mine. These ores must be of smelting grade to be of any value. The zinc smelters require a zinc content of at least 25 per cent in the ore shipped to them. Moreover, as the zinc smelters are all at some distance, it is easily seen that in order to make an ore of this kind yield the miner a profit at present it must run well over 30 per cent in metallic zinc. On that account there is not a very great tonnage of ores containing less than 30 per cent of zinc marketed. The greater part goes to the dumps or is stored in the old stopes of the mines.

The ores of type 5, carrying both oxidized lead and zinc minerals, with gold and silver are in some instances being concentrated. Whatever heavy lead carbonate and silver can be concentrated out by

gravity methods is saved, leaving the zinc and considerable lead and silver in the tailings. These zinc tailings are sometimes shipped to zinc smelters. When the zinc content is low enough (below 10 per cent) they are sometimes shipped direct to a lead or copper smelter.

The ores of type 6, carrying oxidized zinc, lead, and copper minerals with silver and gold, also present a rather serious problem. At present the object sought in milling these ores is to get rid of the zinc entirely. Zinc is a detriment in the metallurgy of most other metals, and ores of high gross value often lie useless on account of the difficulty of separating the zinc from the other mineral constituents. Only those ores in which the zinc content is so low that it will not interfere with smelting the other metals are shipped.

In the ores of type 7, which are partly oxidized, the heavy sulphides can be recovered by ordinary gravity concentration methods, or by flotation. The only loss is in the oxidized minerals, with the exception of the lead carbonate, part of which is also recovered. As previously stated, the Utah Copper Co. in working its ores recovers the sulphides, but not the oxides. However, the company is planning to leach the tailings dumps later to recover the oxides.

COMPLEX SULPHIDE ORES.

The ores of type 8, complex sulphide ores, have been encountered in those camps where the mines have reached the sulphide zone. At Bingham this class of ores is being successfully treated in one instance by wet concentration followed by drying and electrostatic separation, as practiced in the United States mill at Midvale.

At Park City mixed sulphides have been treated, at the Daly Judge mill, by wet concentration, followed by drying, very close sizing, and pneumatic separation. The mixed sulphides from another mine were treated by wet concentration, followed by light roasting and electromagnetic separation.

Smelting mixed sulphide ores in a lead or copper blast furnace is practical only when the zinc content of the ore is less than 10 per cent. When such ores are concentrated, the object is to obtain a rich concentrate with less than 10 per cent of zinc. This concentrate can then be sold to the local smelters, and the zinc middlings can be treated as described above, or else sent to the "blowing up" furnace to be made into paint pigment.

The application of dry chlorination processes to complex sulphide ores is under experiment on a commercial scale at Kellogg, Idaho, and at Helena, Mont. The sulphides are chloridized by heating in contact with chlorine gas. The metals other than zinc are extracted by leaching and deposition. The zinc chloride is concentrated, completely dried, and fused ready for the electrolytic cell. The results of these tests are awaited with interest.

Finally, the complex sulphide ores are also being treated by gravity concentration as well as by the use of electrostatic and magnetic concentrating machines.

REMOVAL OF COPPER.

In those ores in which copper is a cause of complications in the metallurgical treatment there seems now to be a fairly good assurance that it can be removed economically. At many localities in the United States the problem is being solved more or less successfully. On that account the work of the present investigation is lightened to some extent because only the most promising methods need be tried on the Utah ores. As regards the treatment of zincky oxidized ores, that is a more difficult problem. The investigation by the metallurgical research department of the State School of Mines has included keeping in touch with the work of 17 different concerns that are trying to solve practically the same problem. Much pioneer work remains to be done.

CHIEF METALLURGICAL PROBLEMS.

Summing up, then, one may say that although many problems present themselves to those who are attempting to devise processes for economically treating the low-grade and complex ores of Utah, the following seem to be the most difficult:

TREATMENT OF OXIDE AND CARBONATE ORES.

The writers know of no commercially successful process whereby the valuable minerals may be concentrated out of the low-grade oxidized ores. As smelting processes are, for the most part, applicable only to the treatment of materials in which the values are more or less concentrated, it follows that, for the present at least, only hydrometallurgical processes are suited to the treatment of low-grade ores in which the metals are present as oxides or as carbonates. The problem is, therefore, to devise, if possible, hydrometallurgical processes that can successfully and economically treat low-grade oxidized and carbonate ores.

TREATMENT OF ZINC-BEARING ORES.

At present none of the concentrating processes employed effect as close a separation of the zinc and lead in complex sulphide ores as is desirable, as is shown in the table following, taken from a paper^a

^a Lyon, D. A., and Arentz, S. S., Losses of zinc in mining, milling, and smelting: Bull. 91, Am. Inst. Min. Eng., July, 1914, pp. 1422-1423.

by Lyon and Arentz, which was presented at the Salt Lake meeting of the American Institute of Mining Engineers in August, 1914:

Recovery of zinc by various concentration processes.

Process.	Zinc in zinc concentrate.	Zinc in product going to blast furnace.	Proportion of metal recovered.		
			Zinc.	Lead.	Silver.
Ordinary wet concentration:	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Park City, Utah.....	.....	.....	50.0	95.0	75-80.0
Do.....	.....	.....	68.0	92.0	78.0
Burke, Idaho.....	.....	.....	25.0	90.0	85.0
Joplin, Mo.....	.....	.....	ø 65.4	.....	.....
Wetherill, magnetic ^a	50.0	5.0-7.0	.....	.....	.....
Huff, electrostatic: ^b	.....	.....	.....	.....	.....
Midvale, Utah.....	48.0-50.0	10.0	.....	.....	.....
Eureka, Colo.....	41.3	12.6	.....	.....	.....
Sunnyside, Colo.....	49.3	8.6	.....	.....	.....
Potter-Delprat ^c.....	.....	.....	66.2	38.5	50.9
De Bayay: ^d	.....	.....	.....	.....	.....
1910.....	48.1	11.7	.....	.....	.....
1911.....	48.4	14.2	.....	.....	.....
1912.....	49.2	16.6	.....	.....	.....
Elmore vacuum ^e	46.0	15.84	.....	.....	.....
Mineral separation.....	.....	.....	85.4	74.8	80.1
Horwood.....	48.7	10.2	.....	.....	.....
Hyde process:	.....	.....	.....	.....	.....
Butte ^f.....	.....	.....	88.1	.....	83.4
Superior ^f.....	.....	.....	86.4	62.5	80.0

^a Editorial, Magnetic separation of zinc blende at Denver, Colo.: Eng. and Min. Jour., vol. 74, August 16, 1902, p. 217.

^b MacGregor, F. S., Progress in electrostatic ore dressing: Trans. Am. Electrochem. Soc., vol. 24, 1913, p. 352.

^c Hoover, T. J., Concentrating ores by flotation (London), 1912, p. 91.

^d Hoover, T. J., op. cit., p. 97.

^e Hoover, T. J., op. cit., p. 105.

^f Results are for 1913.

ø About.

The following extract is from the same paper:

In presenting these facts as regards the methods which are used for concentrating zinc ores, we do not wish to be understood as criticizing any of the concentration processes mentioned, as they do the work for which they are installed, namely, to separate gold-silver-lead-copper-zinc-bearing ores into two products, one of which shall contain enough zinc to enable it to be profitably treated by the zinc smelter, and the other no more than will permit of its being satisfactorily treated in a copper or lead blast furnace. As is well known, in such furnaces, if the zinc content of the ore constituting the charge is not greater than 10 per cent, it can be gotten rid of in the slag and fumes. The loss of this amount of zinc is, of course, a distinct waste. As to the amount of zinc lost in this manner, the following example will serve to illustrate the same.

If we treat ore containing, say, 28 per cent of zinc, we separate this into two products, one of which will contain, say, 50 per cent zinc, whereas the other will contain most of the gold, silver, copper, and lead and about 10 per cent of zinc. In other words, of our original product of 50 tons we will have 28 tons (more or less, dependent upon the percentage of iron present) of product containing 50 per cent zinc, and 22 tons containing 10 per cent, and, in addition, most of the gold, silver, copper, and lead contained in the original product. This latter product goes to the blast furnace and ordinarily the zinc content is not saved, but is lost in the fume and slag. This amount of zinc therefore

represents a loss of almost 1,500,000 pounds a year. Moreover, this zinc is lost for all time, as it can not be recovered, and when we consider that this is lost from the treatment of only 50 tons of concentrates per day, we can readily understand, as has been shown by those who have investigated this subject, that the zinc lost in this way amounts in the aggregate to thousands of tons annually, and, as has been pointed out by Clevenger^a and others, in the inability to recover this zinc lies one of the greatest weaknesses of our present-day metallurgical practice, in that the zinc so lost represents a distinct economic waste, much of which will never be recovered, and that we must look to the prevention of this waste as one of the sources from which we shall in the future obtain a large part of our zinc supply.

The same thing is of course true to some extent of lead, for in copper smelting, if lead is present, it is volatilized and no attempt is made to recover it, and so the lead is completely lost. As before stated, these facts are not presented with the idea of bringing an indictment against electromechanical methods of concentration, or against modern methods of copper and lead smelting, but rather to emphasize the fact that although mechanical methods of concentration and modern methods of smelting have reached a very high stage of development, their use nevertheless entails a very great loss of zinc, which is not recoverable, and that therefore it is quite likely that in the future it will be necessary to stop these wastes in order to add to the available supply of zinc.

The problem therefore which presents itself is to derive processes which will successfully treat low-grade and complex ores containing zinc.

CHLORIDIZING PROCESSES.

The devising of practicable processes for treating the low-grade and complex ores of Utah has already been given considerable time and attention by various investigators and experimenters. As a result of such work at least two chloridizing processes are being tried out, one of which is known as the Holt-Dern process, and the other the Knight-Christensen process.

HOLT-DERN PROCESS.

The Holt-Dern chloridizing process was discussed by Holt^b in a paper before the August, 1914, meeting of the American Institute of Mining Engineers at Salt Lake City. This discussion has been reprinted in the mining journals and is doubtless available to those who may desire to acquaint themselves with the details of the process as applied at the plant of the Mines Operating Co., at Park City.

F. S. Schmidt^c has also discussed this plant and personal tests made at it, together with operating costs.

^a Discussion by Clevenger, G. H., and others, Is there a complex-ore problem?: *Met. and Chem. Eng.*, vol. 12, May, 1914, p. 299.

^b Holt, T. P., Chloridizing leaching at Park City: *Bull. 91, Am. Inst. Min. Eng.*, 1914, pp. 1699-1708.

^c Schmidt, F. S., Rejuvenating the chloridizing roast: *Min. Sci. Press*, Aug. 29, 1914, pp. 324-328.

PRINCIPAL FEATURES OF PROCESS.

Following is a brief summary of the steps in the process. The ore is ground to 8 to 10 mesh size, mixed with $7\frac{1}{2}$ per cent of salt, $2\frac{1}{2}$ per cent of coal dust, and just enough water to ball up the mixture. This pulp is then given a chloridizing roast in air-blast shaft furnaces. The roasted material is leached with a brine solution containing up to 0.5 per cent of sulphuric acid. The leach solution is passed first over scrap copper to precipitate the silver, and then through a long series of iron boxes. The first of these boxes catches fine copper, the lower ones produce a copper-lead product. From 90 to 95 per cent of the silver and copper are reported to be recovered by the process outlined above, and also about 50 per cent of the gold. Should the gold content be sufficient to warrant the addition of bleach to the pulp over 90 per cent of the total gold content may be recovered.

FACTORS AFFECTING THE PROCESS.

The composition and the other pertinent characteristics of the ore that must be considered in the application of this process to any particular ore will now be discussed.

The results of tests at Park City, and also of many other tests in various parts of the country strongly indicate successful extraction of the gold, silver, and copper contents of low-grade ores, provided that other factors, which are considered below, do not prohibit the operation of the process.

A quartz or porphyry gangue is indifferent to the reactions that take place in chloridizing, and therefore ores high in silica are especially desirable. A limestone gangue or one of dolomite or other magnesium compounds takes such active part in the reactions that ores with such gangues may or may not be amenable to chloridizing methods.

Limestone is detrimental both in the roasting and in the leaching. In the roasting, calcium oxide decomposes the metallic salts and also silver chloride, thus preventing complete chloridization of the metal contents. In the leaching, any undecomposed lime reacts with the acid, thus weakening the solvent power of the leaching solution, for the solvent action of the brine depends on the presence of a small amount of free acid. However, should sulphur be present in the ore or be added, in quantity sufficient to convert the lime, during the roasting period, to chloride or sulphate, a good chloridization of silver and copper may be obtained. In one test an ore containing 23 per cent lime was successfully treated by roasting with an addition of 12 per cent pyrite and 10 per cent salt. This might be taken to indicate that the content of lime need be limited by economic considerations only, the maximum allowable percentage of lime be-

ing determined by the cost of the pyrite and salt necessary. The consideration of lime content suggests another possible solution, namely, the mixing of different ores in suitable combinations.

Magnesium compounds are similar in their action to calcium compounds and the remarks on lime apply to magnesium equally well.

Arsenic and antimony do not seem to be of much importance in a consideration of this process as applied to Utah ores. However, it may be stated that arsenic and antimony compounds when present in small amounts usually volatilize as chlorides.

Zinc sulphide is not affected by chloridizing shaft roasting, whereas zinc oxide is converted to a chloride that is very volatile. Leaching with an acidified brine after roasting recovers less zinc than may be obtained by leaching the raw ore.

Lead sulphide becomes mostly converted to sulphate in the roasting, owing to the oxidizing effect of the air blast. The sulphate does not react with the sodium chloride in roasting. Lead oxide may be formed, capable of being chloridized; but both oxide and chloride are volatile. Although at the Park City plant about 40 per cent of the low lead content (0.72 per cent in original ore) goes into solution, the extraction from solution by means of the iron-box precipitation is stated to be inefficient. Electrolytic methods of precipitating lead are under consideration at that plant.

Pyrite in the ore is advantageous in providing sulphur for the reactions, for neutralizing lime and magnesium, and for combustion, thus lowering the amount of fuel necessary. Sulphur in excess of that necessary for the foregoing purposes lengthens the period of roasting but the sulphur in the escaping fumes may be utilized in the generation of sulphuric acid for the leaching.

Slimy ores that prohibit percolation would require a variation of the Holt process—some method of agitation and vacuum filtration.

Water is required in the reaction, and also to ball up the slime so as to make a product suitable for the furnace charge and a calcine suitable for leaching.

SUMMARY.

The Holt process seems successful as regards extractions of copper, silver, and gold in low-grade ores, and in addition recovers a small part of the lead. The process is especially adaptable to siliceous ores containing pyrite enough to provide the sulphur necessary for the sulphatization that precedes the chloridization.

Limestone and magnesium are detrimental, but ores containing these substances may be successfully treated if sulphur can be economically added.

With the proper conditions as indicated, a recovery of 90 to 92 per cent of the total copper, silver, and gold content, seems usually

possible. As regards copper, silver, and gold, the limit of application of the process within the allowable limits as stated herein will usually be the cost of treatment. Where salt and coal are available at low costs, especially if ores of differing compositions are available for mixing so that the important reactions can be naturally regulated, the chloridizing process should be hard to equal in efficiency.

KNIGHT-CHRISTENSEN PROCESS.

The mines of Godiva Hill produce much siliceous ore carrying silver. Although a market for such ore has been developed through the operation of the basic-lined converter, the amount smelted is comparatively small. The quantity of this ore has encouraged much research on improved methods of treatment. A series of analyses of these ores, accompanied by tests of methods of treatment, was made by N. C. Christensen in the metallurgical laboratories of the University of Utah. As a result of these tests a new mill has been erected just above Silver City for the treatment by the Knight-Christensen process of 100 tons of these siliceous ores daily. At this mill the ore is crushed to 20 mesh, mixed with salt and pyrites, and the mixture roasted in a new type of furnace designed for the chloridizing roasting of this ore. The furnace consists of an annular screen hearth 4 feet wide, 20 feet in outer diameter, and 12 feet in inner diameter. On the hearth a thin layer of limestone is spread and the layer of ore is built up to a depth of 4 inches. A crude-oil burner, which extends across the hearth next to the feed hopper, gives a flame hot enough to start the roasting of the admixed sulphides. The reactions between the salt and the roasting sulphides give a chloridizing atmosphere for the complete chloridization of the silver and copper in the ore. Air is drawn through the roasting mixture by a suction fan and the fumes are carried to the acid towers, where they are absorbed and collected in tower liquors. The acidified liquors are carried to the storage tanks, where they are brought up to the required strength, then being ready for the leaching tanks. The roasted ore is transferred to the leaching tanks and the silver and copper are leached out with the acidified salt solution. The metals are thrown down by means of scrap iron in a series of tanks that extend lengthwise of the building. The spent liquors are used again for leaching a new batch of ore, after being brought up to proper strength in the towers, by the addition of the necessary salt.

The novel feature of the mill is the method of chloridizing the ore and the use of salt acid tower liquors for leaching.

The successful operation of this mill is anxiously awaited by the many mine owners near by who have an abundance of ore of similar character.

PROCESSES HAVING A POSSIBLE APPLICATION TO UTAH ORES.

One of the first things done by the department of metallurgical research of the University of Utah, was to make a search, as thorough as the facilities of the university library would permit, for information on processes that might possibly be applied to the treatment of the low-grade and complex ores of Utah. The literature relating to patents on the subject was also studied. In the following statement an attempt is made to outline concisely the possible application to Utah ores of processes which are now in use, or have been suggested.

LEAD CARBONATES CARRYING SILVER.

Analysis of the ores treated at the old Ontario mill in Park City shows much lead and silver. Only a very small proportion of the lead is being recovered and its recovery constitutes one of the problems that now face the management. It is somewhat doubtful if a chloridizing and leaching process can recover the lead in these ores, as has been mentioned elsewhere in this report.

MUREX PROCESS.

A process of considerable interest known as the Murex process has been described lately which, it is claimed, will recover lead carbonates. This process combines oil selection and magnetic separation.

SULPHIDIZING AND FLOTATION.

Preliminary tests have indicated the possibility of recovering lead carbonate by "sulphidizing and flotation." The method involves a conversion of the oxidized lead minerals into sulphides by means of hydrogen sulphide gas, which is cheap, followed by ordinary flotation of these artificial sulphides. Further work is to be done along this line and the indications are that the method may be a success.

ELECTROSTATIC SEPARATION.

Electrostatic separation of the lead carbonates carrying silver is another method which has not been tested completely. As it is possible to modify the outside coating on particles of lead carbonate by the sulphidizing process mentioned above, they ought to act as conductors and hence allow electrostatic separation from the gangue minerals in case it is not possible to separate them by flotation, as above mentioned.

OXIDIZED COPPER ORES CARRYING GOLD AND SILVER.

CHLORIDIZING AND LEACHING.

As may be seen by reference to other parts of this report, the chloridizing and leaching process is especially applicable to oxidized copper ores carrying gold and silver, and high extractions of all three metals can be obtained, provided the ore is not too basic.

SULPHIDIZING AND FLOTATION.

Sulphidizing and flotation of these oxidized copper minerals also seems to be possible. Preliminary tests have resulted favorably, and further tests are proposed. The presence of a basic gangue would not affect this process in the least, as hydrogen sulphide does not attack limestone. The process would hence be desirable because of its applicability to ores of almost every kind of gangue.

MOSHER-LUDLOW PROCESS.

The Mosher-Ludlow process was worked out for those ores under consideration which have a basic gangue, and involves leaching with ammoniacal solution carrying cyanide. The ammonia dissolves copper and the cyanide dissolves gold and silver. Precipitation of the copper is effected by boiling, the ammonia being recovered. Tests indicate a high extraction of all three metals and a low consumption of ammonia and cyanide. This process has not yet been used on a commercial scale and there is some question as to the difficulties of handling it in a large mill.

SLATER PROCESS.

Another process that may apply equally well to basic and acid ores is the Slater process, as the leaching agent is hypochlorous acid, which dissolves copper and gold but does not attack calcite. The process is being developed by the Western Precipitation Co., which is to test representative samples of Utah ores. Tests indicate a good extraction of the metals but difficulties still remain as regards the type of cells to be used in generating the hypochlorous acid.

OTHER PROCESSES.

Other special processes are possible, such as the leaching of the copper with dilute sulphuric acid and the cyaniding of the tailings. As a rule those ores of copper, silver, and gold that present a problem to the metallurgist are the ones that are too low grade to smelt, and, as a rule, the problem in cyaniding them is high recovery with-

out a great consumption of cyanide through the action of copper minerals. Preliminary leaching of the copper is hence one logical solution, and will be tried out in a mill at Dayton, Nev., in the near future.

OXIDIZED ZINC ORES, OCCASIONALLY CARRYING GOLD AND SILVER.

IGNEOUS CONCENTRATION.

Igneous concentration seems at present one of the most feasible methods of concentrating earthy oxidized zinc ores, occasionally carrying gold and silver. It involves the use of blast grates, such as are used in the manufacture of zinc-oxide pigment. Very few experiments have been made with this method, but it is believed that the cost of treatment can be reduced to a small figure, enabling the treatment of low-grade ores of zinc. Any gold or silver remains, of course, in the residue left after removal of the zinc, and can then be recovered by smelting. In case the gold and silver contents were too small to make smelting the residue profitable, special processes would have to be devised to recover them.

LEACHING WITH AMMONIUM CARBONATE SOLUTION.

Leaching out the zinc with a solution of ammonium carbonate and ammonia is easily accomplished when the oxidized zinc mineral consists of smithsonite, the carbonate of zinc, but the silicates of zinc are not attacked. Gold and silver can then be leached from the residue or it can be smelted. Some rather extensive tests of this process have been made at Ingot, Cal.^a

BISULPHITE PROCESS.

At Swansea, Wales, a process has recently been brought to more or less technical success whereby zinc is dissolved in a solution of sulphur-dioxide gas obtained by passing the gases from the roasting of sulphide ores through a falling spray of water in a tower. The zinc dissolves in this solution and is easily recovered. Where the oxidized ores can be treated in conjunction with sulphide ores, this process promises to have some value, if sufficiently low costs are indicated by present experiments in Wales. No tests of Utah ores have as yet been made.

LEACHING WITH ACID SOLUTION AND ELECTROLYTIC PRECIPITATION OF ZINC.

A great many processes are being tried out in which either sulphuric or hydrochloric acid is used as a solvent for zinc, the zinc

^a Bretherton, S. E., The treatment of complex ores by the ammonia-carbon dioxide process: Bull. Am. Inst. Min. Eng., July, 1914, p. 1771.

being later precipitated from solution by an electric current. Success will depend on very careful engineering, as the amount of electric energy necessary to precipitate zinc is large in comparison with the value of the resulting metal. Large scale production and cheap electric energy and acid will have to be obtained to insure financial success. Technically these processes work very well.

OXIDIZED ZINC-LEAD ORES, CARRYING OCCASIONALLY GOLD AND SILVER.

The main problem in treating oxidized zinc-lead ores, carrying occasionally gold and silver, is to obtain the zinc and the lead as separate products. On that account processes in which only one of these metals is dissolved are preferable.

BISULPHITE PROCESS.

The bisulphite process previously mentioned dissolves only the zinc and was, in fact, devised for the treatment of complex zinc-lead sulphides. The zinc is dissolved out and precipitated. The residue left contains all the lead, silver, and gold of the ore and can be smelted in an ordinary lead blast furnace. The metallurgical research department plans to try this process on the Utah ores later.

LEACHING WITH AMMONIUM CARBONATE SOLUTION.

In leaching with ammonium carbonate solution the zinc is separated from the other metals as in the bisulphite process. As zinc interferes with the metallurgy of almost all of the other metals, this process would seem to be a desirable one for such ores.

SULPHIDIZING AND FLOTATION.

Sulphidizing and flotation, as previously mentioned, has been found to remove lead minerals but not to affect zinc minerals, and hence offers another method of separating lead and zinc. As the silver and gold are quite likely to accompany the lead, the process would seem to offer a most desirable type of mechanical concentration, provided the lead and zinc minerals can be separated from each other by sufficiently fine grinding.

OXIDIZED ORES OF ZINC AND COPPER, CARRYING GOLD AND SILVER.

LEACHING WITH AMMONIUM CARBONATE SOLUTION.

In the ammonium carbonate process described both the zinc and copper are dissolved, but they are easily separated by electrolysis as the metallic copper will deposit on the zinc. The gold and silver will remain in the residue, and can be recovered by leaching or smelting. Tests of this process on the Utah ores have not been made as yet by the metallurgical research department of the University of Utah.

BISULPHITE PROCESS.

The bisulphite process will also dissolve both the copper and the zinc, and as they are easily separated, the remarks on the ammonium carbonate process apply here as well.

LEACHING WITH ACID SOLUTION AND ELECTROLYTIC PRECIPITATION.

Leaching out the zinc and copper with acid solution, followed by electric precipitation of the zinc and copper, separately, seems feasible. Copper can be precipitated completely in the presence of zinc without any zinc being precipitated, because the voltage required to decompose the zinc salts is much higher than that required for the copper salts.

IGNEOUS CONCENTRATION.

Igneous concentration of the zinc content is supposed to be perfectly feasible with these ores, the copper, gold, and silver being left in the residue. As this residue is likely to be partly fused, nothing but smelting can recover the copper, gold, and silver. Hence the ore must be of high enough grade to stand the smelting costs; otherwise, one of the leaching processes should be better.

OXIDIZED ORES CARRYING ZINC, COPPER, LEAD, SILVER, AND GOLD.

In these ores, the presence of zinc is again the disturbing factor, and its removal separate from the other metals eliminates most of the difficulty. As mentioned above, both the bisulphite process and the ammonium carbonate process under certain conditions remove zinc and copper, and these two metals are easily separated from each other. It would therefore seem feasible to apply these two processes to this class of ores. Sulphidizing and flotation would seem to be a very promising method of removing the lead, copper, gold, and silver from the zincky residue.

PARTLY OXIDIZED SULPHIDE ORES.

Very few of the processes mentioned work well on both sulphide and oxidized ores except igneous concentration, which should remove zinc as a clean product from any ore that is not too high in lead. All of the other processes discussed would doubtless require the ore to be roasted before they could be applied. Also, most of the sulphide minerals could be removed by ordinary methods of gravity concentration before processes for the oxidized minerals were applied.

RAW MATERIALS FOR USE AS REAGENTS.

The State of Utah has within its borders abundant supplies of minerals that may be employed as reagents in processes for extract-

ing metals from ores. The tremendous salt supply in the waters of the Great Salt Lake and in the deposits near by was for many years put to good use in the ore-reducing mills. New processes employing increased amounts of salt are coming into use. The salt and associated mirabilite (NaSO_4) will serve as the raw material from which chemical works can make sodium carbonate, hydrochloric acid, hypochlorous acid, iron chloride, and such chlorides, perchlorates, chlorates, etc., as may be needed in leaching ores. A process for the manufacture of hydrochloric acid from common salt, silica, and steam has been evolved in the research laboratories of the university which bids fair to provide for making this acid at a cost well below the present cost of manufacture. The sulphur gases from smelter smoke carry the constituents for the manufacture of sulphuric acid, the acid most used in leaching plants. In localities near plants smelting sulphide ore the price of sulphuric acid may possibly be brought to a nominal figure. The removal of sulphur gases from smelter fumes to make sulphuric acid will largely reduce the harmful effects of smelter smoke on vegetation.

IRON FOR PRECIPITATION.

By a process of chemical replacement the gold, silver, and copper of the leaching solutions may be deposited by metallic iron. Scrap iron has been used extensively in regions where it is cheap. In the mining districts of Utah the amount of scrap iron to be obtained would be very small.

Within the State, accessible from Salt Lake City and vicinity, are large amounts of ores suitable for the production of sponge iron, as both sulphide and oxidized iron ore and copper-bearing sulphides are suitable for this purpose. An economic saving is made if the ores contain gold, silver, or copper, these metals being all saved, and without added cost, if the iron, preferably sponge iron, made from the ores is used as a precipitant in leaching processes.

In the July, 1914, number of the Bulletin of the American Institute of Mining Engineers Frederick Laist and F. F. Frick present the following description^a of a method they worked out for the manufacture of sponge iron:

The furnace, a Brückner type, 4 feet 3 inches in diameter inside and 7 feet long, is operated as follows:

One thousand four hundred pounds of calcine are charged and heated with fuel-oil flame to about $1,300^\circ \text{F}$. This requires about one and one-fourth hours. In a commercial plant the calcine would be drawn hot directly from the MacDougall hoppers to the furnace. About 600 pounds of coal are then shoveled in through the front in small lots. The furnace continues to revolve, and in about three-quarters of an hour after starting to charge the coal the hydro-

^a Precipitation of copper from solution at Anaconda, p. 1433.

carbons are burned off. The oil flame is again started. In one and three-fourths to two hours the charge is up to $1,680^{\circ}$ to $1,700^{\circ}$ F., and reduction is complete. The discharging door is removed and the charge quenched.

SODIUM SULPHATE (MIRABILITE).

Next to common salt, sodium sulphate suggests itself as a profitable product of the water of Great Salt Lake.^a This substance (known mineralogically as mirabilite) separates from the brine at a certain low temperature. This critical temperature is probably within a few degrees of the freezing point of fresh water.

As the crystallization of the mirabilite proceeds the water becomes opalescent, and the substance deposits over the lake bed and is cast up by the waves in such quantities as to cover the shore in places to a depth of inches or even feet. It can be easily gathered by the use of horse drags.

The easy preparation of sodium carbonate from mirabilite is self-suggestive, and experience has demonstrated the success of the undertaking at low cost. Limestone and coal necessary to transform the sulphate into carbonate are of easy access.

ALLIED PROBLEMS.

In taking up an industrial problem one generally finds that there are many allied problems awaiting solution, and this has proved to be especially true of the investigation to ascertain the feasibility of attempting to treat the low-grade and complex ores of the State of Utah. To illustrate—certain electrometallurgical processes demand cheap power. Such being the case, information is needed as to the availability of electric power either from the utilization of flowing streams or from the coal resources of the State. Again, with the question of hydroelectric power may be connected the question of irrigation, as at The Dalles, Oreg., and the working up of this possibility alone may require considerable investigation. If coal is to be utilized, the location of available coal beds, the nature of the coal, and the possible utilization of the by-products from the distillation of the coal become of interest.

Incidentally, the problem of utilizing such by-products of coal as ammonia, tars, and tar oils is closely connected with metallurgical processes, as ammonia can be used very well in the extraction of metals from oxidized ores, both of copper and of zinc, and certain coal-tar products are in demand for flotation work. A proper investigation might show that it would prove profitable to save these materials in the coking of the coals instead of letting all of the volatile part of the coal be wasted, as it is at present in the preparation of coke in Utah, Nevada, Idaho, and Montana.

^a Talmage, J. E., *The Great Salt Lake*, 1900, pp. 64-65, 82-86.

In the coking of coal it may be possible to find a solution of the smoke problem in the city of Salt Lake, as coke and gas fuels are smokeless, whereas the raw soft coals of the State, which are now being used, make the city atmosphere very smoky under certain conditions in wintertime. The department of metallurgical research, in cooperation with the Federal Bureau of Mines, is at present engaged in an investigation of this nature.

Again, as regards the use of electric energy in the preparation of solvents from the waters of Great Salt Lake for the purpose of treating ores, there are likely to be by-products formed which can be used in other industries in the State. As an instance, sodium hydrate, chlorine, or hydrochloric acid can be used in making phosphate rock soluble and available for use as fertilizer, although this can also be done with sulphuric acid, which can be cheaply made by treatment of the smoke from furnaces for sulphide ores.

As is well known, in the eastern part of the State are extensive deposits of hydrocarbons. In hydrometallurgical work it is generally necessary to use large vats. Concrete has proven satisfactory for the construction of such vats, but if acid solutions be used, the vats must, of course, have an acid-proof lining. It is stated that the use of asphalt for this purpose has given excellent results. Hence the hydrocarbons of Utah may become an important source of acid-resistant lining.

A large number of such instances might be cited to show how investigations conducted for the purpose of solving the low-grade ore problem may result in the discovery of unsuspected uses for other natural resources of the State.

CONCLUSION.

As shown by its title, this paper is offered only as a preliminary report. Its purpose is to give some idea of the size and extent of the low-grade ore deposits of the State, and the necessity of conducting investigations for the purpose of discovering processes that will be commercially suited to the treatment of these ores and of developing such other industries as may be brought about as the result of carrying on the investigations.

PUBLICATIONS ON TREATMENT OF MINERALS.

A limited supply of the following publications of the Bureau of Mines is temporarily available for free distribution. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp., 6 figs.

BULLETIN 47. Notes on mineral wastes, by C. L. Parsons. 1912. 44 pp.

BULLETIN 53. Mining and treatment of feldspar and kaolin in the southern Appalachian region, by A. S. Watts. 1913. 170 pp., 16 pls., 12 figs.

BULLETIN 64. The titaniferous iron ores of the United States, their composition and economic value, by J. T. Singewald, jr. 1913. 145 pp., 16 pls., 3 figs.

BULLETIN 70. A preliminary report on uranium, radium, and vanadium, by R. B. Moore and K. L. Kithil. 1913. 101 pp., 4 pls., 2 figs.

BULLETIN 71. Fuller's earth, by C. L. Parsons. 1913. 38 pp.

BULLETIN 77. The electric furnace in metallurgical work, by D. A. Lyon, R. M. Keeney, and J. F. Cullen. 1914. 217 pp., 56 figs.

BULLETIN 81. The smelting of copper ores in the electric furnace, by D. A. Lyon and R. M. Keeney. 1914. 80 pp., 6 figs.

BULLETIN 84. Metallurgical smoke, by C. H. Fulton. 1914. 90 pp., 5 pls., 15 figs.

TECHNICAL PAPER 41. Mining and treatment of lead and zinc ores in the Joplin district, Missouri, a preliminary report, by C. A. Wright. 1913. 43 pp., 5 figs.

TECHNICAL PAPER 50. Metallurgical coke, by A. W. Belden. 1913. 48 pp., 1 pl., 23 figs.

TECHNICAL PAPER 60. The approximate melting points of some commercial copper alloys, by H. W. Gillett and A. B. Norton. 1913. 10 pp., 1 fig.

TECHNICAL PAPER 81. The vapor pressure of arsenic trioxide, by H. V. Welch and S. H. Duschak. 1915. 22 pp., 2 figs.

TECHNICAL PAPER 88. The radium-uranium ratio in carnotites, by S. C. Lind and C. F. Whittemore. 1915.

TECHNICAL PAPER 95. Mining and milling of lead and zinc ores in the Wisconsin district, by C. A. Wright. 1915. 39 pp., 1 pl., 5 figs.



